(54) Auxiliary gas turbine engines

(57)   An auxiliary gas turbine engine comprises: a load compressor 110; a cabin air supply duct 115 which supplies at least some of the air from the exit of the load compressor 110 to the aircraft cabin; a high pressure (HP) compressor 120 which further compresses the remaining air from the exit of the load compressor 110; a combustor 130; a turbine 140; an electrical generator 150 driven by the turbine 140; an electric motor 160 driven by the electrical output of the generator 150, the electric motor 160 in turn driving the load compressor 110; and at least one air heater/cooler 170A, 170B or 170C comprising a heat exchanger matrix 172A, 172B or 172C located in the appropriate air duct and a reversible refrigeration plant or heat pump 174A, 174B or 174C which is electrically powered from the generator 150 so that it can either cool or heat the air passing through the matrix. The load compressor and heat exchanger(s) together produce air at the required pressure and temperature for supply to the aircraft cabin.

FIGURE 1

ALTERNATIVE CONFIGURATION 1

Electrical Offtake

Exhaust 147

Generator 150

155

129

140 Turbine 145

Staged Combustor 130

131 132 133

Aircraft Duct 126

Recuperator 128

Motor 124

120 122

Aircraft Cabin 113

112

HP Compressor

115

Inlet Air Heater/Cooler 170A

Motor 172C

160

174A

174C

110 Load Compressor

LP Air Heater/ Cooler 170C

105

172A

Air Inlet 107
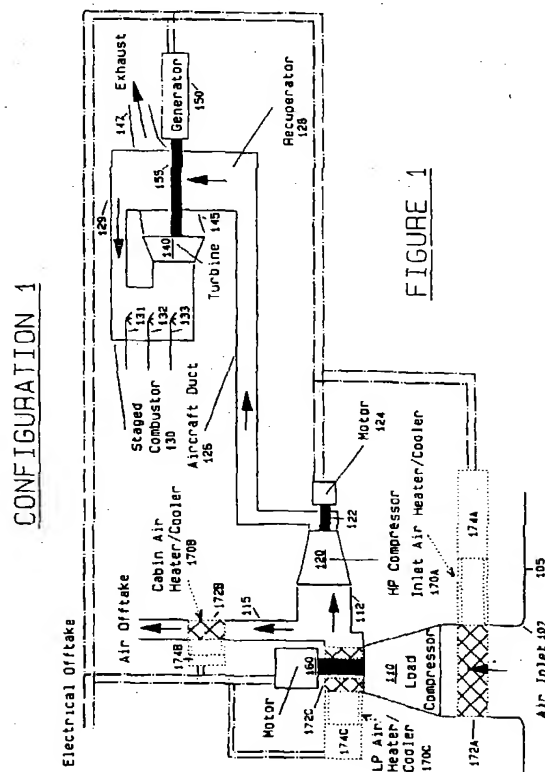
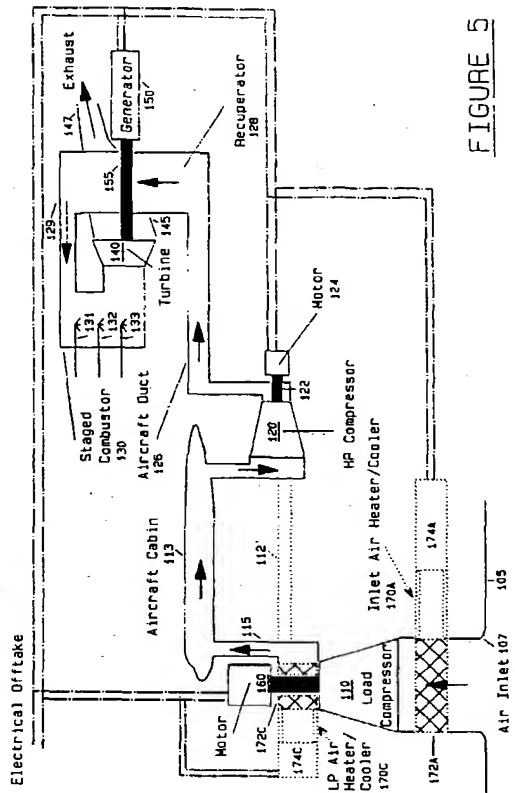FIGURE 5

Descripti n

TECHNICAL FIELD

5   This invention relates generally to auxiliary gas turbine engines for aircraft, particularly civil passenger transport aircraft.

BACKGROUND ART

10   Civil passenger transport aircraft are provided with cabin pressurisation and air conditioning systems and electrical power supply systems. It is usual for main turbojet, turboprop or turbofan propulsion engines to have one or more offtakes from their compressors for supply of compressed air to the cabin pressurisation and air conditioning systems. The main engines are also used to drive an electrical generator to provide electrical power.

        Auxiliary power units (APUs) were at one time provided solely for use while aircraft were on the ground, to render
15   them independent of ground-based air and power sources. Later, it was considered sensible to utilise APUs as backup sources of air and power during flight to take air and power offtake loads away from the main propulsion engines if one or more of them failed. This required the APUs to have a more sophisticated design because they had to be startable at high altitudes and low temperatures.

        More recently, it has been proposed that APUs be utilised to help to optimise fuel burn of the main engines during
20   descent from cruise altitude. This proposal recognises that, due to the low propulsive thrust required in the descent phase of flight, the lowest attainable throttle setting is that necessary to supply aircraft pressurisation, air conditioning and electrical power demands from the main engine air offtakes and electrical generators. Consequently, the main engines produce more propulsive thrust than is needed, thereby slowing the rate of descent and using more fuel. In such a situation, APUs can be utilised to reduce fuel burn by starting them before beginning the descent phase, thus
25   enabling the engines to be throttled back to minimum thrust. This gives a faster descent, which can also be initiated later in the flight, so further reducing total fuel burn per flight.

        Due to continued growth in aircraft passenger capacity, allied with the adoption of large twin engined aircraft for passenger transport, the number of passengers supplied with air and power from each main engine has tended to increase. At the same time, improved efficiency in turbofan engines, allied with continued increases in bypass ratios,
30   has increased the proportion of air which bypasses the compressor, so that air offtakes for pressurisation and air conditioning have become a larger fraction of the airflow through the compressor. Increasingly, accommodation of the air offtakes requires special compressor design measures to reduce the likelihood of flow instabilities as the offtake air demand varies.

        A further difficulty associated with air offtakes from the main engine compressors is in the installation of the ducting
35   required to bring the compressed air from the engines to the pressurised hull. Drag minimisation requires that support structures such as pylons have low frontal area and are elongated in the direction of flight, but the need to install air ducting in them increases frontal area above that needed solely for structural reasons.

        Following from the above, an object of the present invention is to provide aircraft with fuel efficient, high performance auxiliary gas turbine engines which are operational on the ground and throughout the aircraft's flight envelope to supply
40   all or at least a substantial proportion of the aircraft's pressurised air and electrical power requirements, thereby allowing greater optimisation of the performance of the main propulsion engines for propulsion purposes.

        Another object of the invention is to reduce or eliminate the need for air ducting in the wings and the main engine support structures.

        A further object is to reduce the installed weight of the main propulsion engines in an aircraft by reducing or elimi-
45   nating the need for them to drive associated electrical power generators and by reducing or eliminating the engine ducting, valves and control means associated with air offtakes from the main engine compressors.

        A major object is to enable better design optimisation of an auxiliary gas turbine engine's component parts. A related object is to enable flexibility in positioning of an auxiliary gas turbine engine's component parts with respect to the airframe in which it is installed.

50   A particularly desirable object of the invention is to increase passenger comfort by enabling design of auxiliary gas turbine engines which can supply more air per passenger than is currently supplied by air offtakes from main propulsion engines.

SUMMARY OF THE INVENTION

55

        According to the present invention, an auxiliary gas turbine engine for an aircraft includes:
        an air intake,
        a load compressor for compressing air supplied from the air intake,

a cabin air supply duct for supplying at least some of the air from the load compressor as air to the aircraft cabin,

a combustor for burning fuel in air supplied by the load compressor,

a turbine driven by the combustion products of the combustor,

turbine exhaust means,

variable speed drive means for transferring power from the turbine to drive the load compressor, and

heat exchanger means for adjusting the temperature of the air before use in the aircraft cabin.

The term "load compressor" is used because the air requirement for the cabin is a load on its output of compressed air and to distinguish it from any further stage of air compression which may be present in the engine.

The variable speed drive means enables the load compressor to be run at a speed which is independent of the speed of the turbine and therefore at a suitable pressure ratio to produce air at the correct pressure for pressurisation of the aircraft cabin, whereas the heat exchanger means enables adjustment of the temperature of the air passed from the load compressor to the cabin to obtain the correct temperature for the cabin. The load compressor and heat exchanger means work together to produce air at the required pressure and temperature without further air conditioning being required, other than humidity control, which is not currently provided in aircraft for weight reasons.

Preferably, the load compressor is in flow series with a high pressure (HP) compressor, the load compressor acting to supercharge the HP compressor and the HP compressor supplying air to the combustor. The HP compressor may be driven either directly by the turbine, or by transfer of power from the turbine through further variable speed drive means.

Since the load compressor is not directly driven by the turbine, it can, if desired, be positioned remotely from the HP compressor and/or the combustor, with air being carried between these components by ducting. In some embodiments of the invention, the aircraft cabin itself may be used to carry some or all of the air passing from the load compressor to the HP compressor and/or the combustor. Similarly, if the HP compressor is not directly driven by the turbine, it can also be positioned remotely from the the combustor, if desired.

To maximise flexibility in layout within the airframe, and to minimise both weight and loss of overall engine efficiency, variable speed drive means for transmitting power from the turbine to the load compressor preferably comprises an electrical generator driven directly by the turbine, and an electric motor driven by the electrical output of the generator, the electric motor in turn driving the compressor.

Similarly, the further variable speed drive means for transmitting power from the turbine to the HP compressor preferably comprises a further electric motor driven by the electrical output of the generator, the electric motor in turn driving the HP compressor.

It is preferred that the electrical generator also supplies the electrical power requirements of the aircraft.

Alternative variable speed drive means can be envisaged within the ambit of the invention, such as geared, hydraulic and pneumatic drives for transferring power from the turbine to a compressor. Such mechanical, hydraulic or pneumatic power transfer could be used in conjunction with a turbine driven electrical generator for supplying the electrical power requirements of the aircraft.

The heat exchanger means includes a heat exchanger matrix located before and/or after the load compressor to either cool or heat the air passing through the matrix. If required for adequate control of cabin air temperature, the heat exchanger means further includes a heat pump powered through drive means from the turbine so that it can either cool or heat air passing through the matrix. Preferably, the drive means for the heat pump comprises an electric motor driven by the turbine-driven electrical generator.

As an alternative to the use of a heat pump to heat the air passing through the heat exchanger matrix, the matrix could incorporate electrical heating elements drawing power from the generator.

In a first variation of engine layout, a heat exchanger matrix of the heat exchanger means is located in the air intake to heat or cool the air before it enters the load compressor. In a second variation of engine layout, a heat exchanger matrix is located in the cabin air supply duct to heat or cool the air after it has passed through the load compressor but before it is used for air conditioning of the aircraft. In a third possible variation, a heat exchanger matrix is located at the outlet of the load compressor to heat or cool all the air after it has passed therethrough, before it enters the cabin air supply duct and the HP compressor, if present.

The above three locations for a heat exchanger matrix are not mutually exclusive and may be used in any advantageous combination. This enables switching of the heating or cooling effect to the optimum position for a given flight condition. In particular, it may be advantageous to locate a heat exchanger matrix in the air intake and modify its effect by a further heat exchanger matrix located in the cabin air supply duct or at the outlet from the load compressor.

In some embodiments of the invention, the aircraft cabin is used to carry some or all of the air passing from the load compressor to the HP compressor and/or the combustor. In this case, there are only two locations required for effective use of heat exchangers, i.e., before the load compressor (in the air intake) and at the load compressor's outlet. In these embodiments, a heat exchanger at the load compressor's outlet would have to adjust the temperature of all air passed out of the load compressor to that required in the cabin.

To increase the engine efficiency and reduce fuel consumption, an exhaust heat recuperator may be employed to heat the air from the compressor(s) before it enters the combustor. Preferably, the recuperator comprises a heat ex-

change matrix built into the turbine outlet duct.

To minimise emissions of pollutants from the combustion process, the combustor may be of the lean burn type.

The invention further includes an aircraft having installed therein an auxiliary gas turbine engine as described above.

BRIEF DESCRIPTION OF THE DRAWINGS

Exemplary embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of one basic configuration of an auxiliary gas turbine engine according to the invention, showing how various component parts of the engine may be connected together;

Figures 2 and 3 are similar diagrams illustrating two alternative basic configurations which may be employed in accordance with the invention;

Figure 4 is a schematic diagram of a known type of auxiliary gas turbine engine; and

Figures 5 to 7 illustrate an alternative implementation of each of the three basic configurations shown in Figures 1 to 3 respectively.

DETAILED DESCRIPTION OF DRAWINGS

Prior Art APU Configuration

In Figure 4, a known common type of APU installed, e.g., near the tail of a civil passenger aircraft comprises, in flow series; an air inlet 407 in an external surface 405 of the aircraft, a compressor 410, a single stage combustor 430, a turbine 440 and an exhaust nozzle 447 from which exhaust gases exit to atmosphere. The turbine 440 may be of the centrifugal or the axial flow type and if the latter will consist of one, two or more rotating stages of turbine blades. The compressor 410 may be of the centrifugal or the axial flow type and if the latter will consist of several rotating stages of compressor blades. Compressor 410 and turbine 440 are mounted on a common shaft 442 so that the turbine, driven by expanding high temperature combustion gases from the combustor 430, in turn drives the compressor 410 to compress the air before combustion.

Combustor 430 burns ordinary aviation fuel in the air supplied by compressor 410. The combustion process is of the conventional rich burn, diffusion flame type, with dilution air added downstream of the burner nozzles 431, 432 to encourage complete combustion and to partially quench the combustion process before excessive amounts of oxides of nitrogen can be produced. Nevertheless, appreciable amounts of pollutants may be produced by this type of combustion process.

Some of the air at or near the high pressure end of the compressor 410 can be selectively bled off into an air supply duct 415 for use in air conditioning of the passenger cabin, and/or for de-icing flight and control surfaces of the aircraft.

Extending from the front of the compressor 410 is a shaft 444, whereby power from the turbine 440 in excess of that needed to drive compressor 410 is used to drive an electrical generator 450, sometimes through gearing (not shown). This provides electrical power for aircraft systems.

In this arrangement, the turbine and compressor are both running at the same rotational speed, which will not be optimum for both components throughout the APU's operational range.

Power Ratings of Configurations 1 to 3 and Alternative Configurations 1 to 3

With respect to the amount of power generated by the auxiliary gas turbine engines described with reference to the accompanying Figures 1 to 3 and 5 to 7, the performance calculations underlying the description assume that each is sized so that two of them are able to supply all the air conditioning and electrical power requirements for a large twin-engined civil passenger transport aircraft. Two auxiliary gas turbine engines have been specified in order to meet the same reliability criteria as are imposed by international airworthiness authorities' regulations in respect of extended range twin-engine operations (ETOPS) for the main propulsion engines of civil passenger transport aircraft.

Hence, with respect to electrical power for aircraft and passenger services, it has been assumed that each auxiliary gas turbine engine must supply a total power of 400kW. With respect to air conditioning capability, such an aircraft can typically carry a total of 375 passengers. Using current cabin air supply technology, each passenger is assumed to require about 0.8 lb/min of cabin air each, a total of about 300 lb/min of air. However, particularly with a full passenger load, cabin air quality tends to be somewhat worse than in an ordinary indoor environment at the same temperature and

pressure. In fact, some stale air is usually recirculated through the cabin to reduce the amount of air required to be taken from the main propulsion engines. Consequently, to improve passenger comfort, it will be assumed for the purposes of the present description that each passenger requires 1.2 lb/min of air each, 50% more than current practice, requiring each auxiliary gas turbine engine to supply 225 lb/min.

The auxiliary gas turbine engines of the Figures 1 to 3 and 5 to 7 are designed to supply air to the aircraft cabin at a temperature of (typically) 24°C and a pressure which is the lesser of sea level (14.696 psia) or a predetermined amount above the ambient pressure at the altitude at which the aircraft is flying. Typically, cabin pressure is 7.5 psi above ambient during cruise, but the exact value is determined by the maximum differential pressure between inside and outside that the cabin structure can safely withstand.

Generic Description - Configurations 1 to 3 and Alternative Configurations 1 to 3

Performance calculations have been carried out for three basic configurations of auxiliary gas turbine engine, each basic configuration having five variations. Each of Figures 1 to 3 illustrate three variations of a respective basic configuration, whereas each of Figures 5 to 7 illustrate a further two variations of an alternative implementation of each of the three basic configurations of Figures 1 to 3. In the Figures, components with similar functions in the different engine configurations are given similar reference numbers, but preceded by a configuration prefix number. For example, each of the basic engine configurations 1 to 3 in Figures 1 to 3 and 5 to 7 respectively have a low pressure (LP) or load compressor. In Figures 1 and 5 its reference number is 110, in Figures 2 and 6 its reference number is 210, and so on. In the following description, when it is desired to make reference to a component irrespective of engine configuration, but which occurs in some form in at least two of the configurations, the configuration prefix numbers will be omitted, e.g., "load compressor 10".

In all three illustrated basic configurations of the invention, the following components of the auxiliary gas turbine engine are present in some form (though their construction, location or mode of operation may differ between configurations, as described later): an air inlet 07, a load compressor 10; a cabin air supply duct 15 for supplying some or all of the air from the exit of the load compressor 10 to the aircraft cabin; a high pressure (HP) compressor 20 which further compresses the remaining air from the exit of the load compressor 10; a combustor 30 which burns ordinary aviation fuel in the air supplied by the HP compressor 20; a turbine 40 driven by the combustion products of the combustor; an electrical generator 50 driven through a shaft 55 by the turbine 40; an electric motor 60 driven by the electrical output of the generator 50, the electric motor 60 in turn driving the load compressor 10; and an air heater/cooler 70A or 70C comprising a heat exchanger matrix 72A or 72C located in the appropriate air duct and a reversible refrigeration plant or heat pump 74A or 74C which is electrically powered from the generator 50 so that it can either cool or heat the air passing through the matrix.

In each of Figures 1 to 3, there are three positions A,B,C shown for an air heater/cooler 70, all shown in dotted lines in each Figure. However, in Figures 5 to 7 - due to use of the aircraft cabin to duct some or all of the air between the load compressor 10 and subsequent components of the auxiliary gas turbine engine - there are only two positions A and C for an air heater/cooler 70, again shown in dotted lines.

In position A, an air heater/cooler 70A heats or cools the air before it enters the load compressor. In position C, an air heater/cooler 70C is sited at the outlet of the load compressor 10 to heat or cool all the air exiting therefrom, before it enters the cabin air supply duct 15 and the HP compressor 20. In position B (Figures 1 to 3 only), an air heater/cooler 70B, comprising a heat exchanger matrix 72B, is located in the cabin air supply duct 15. It is linked to a reversible refrigeration plant or heat pump 74B electrically powered from the generator 50, so that it can either cool or heat the air supplied to the cabin after its exit from the load compressor 10 without affecting air separately supplied through duct 12 to the downstream components of the auxiliary gas turbine engine.

The implications in terms of the performance of the auxiliary gas turbine engines incorporating these variations will be detailed later. However, it should be noted here that air heater/coolers 70B or 70C may be used to modify the effect of air heater/cooler 70A, rather than to substitute for it.

In all three illustrated basic configurations, the load compressor 10 is driven by the electric motor 60 and is remotely sited from the combustor 30, the turbine 40 and the electrical generator 50. This layout differs from the compact design usually employed for auxiliary power units (APUs) in aircraft, in which the whole unit is contained within a single housing and is localised in one part of the aircraft. Although separation of the load compressor from other parts of the power unit in designs according to the present invention does impose some losses in unit efficiency due to the need for ducting to connect the separated components, it is found that such losses are acceptable for the following reasons.

(1) The load compressor can be sited in a more convenient place in the aircraft, so minimising both the length of ducting required to bring air from outside the aircraft to the inlet of the load compressor, and the length of ducting required to supply air to the cabin.

(2) In distinction from the normal layout of an APU, the invention provides separate load and HP compressors running on different shafts, whose rotational speeds can vary separately. Plainly, their relative speeds can be optimised for greatest efficiency to maximise the pressure ratio attainable in each. Furthermore, the load compressor provides all the cabin air requirement while acting as a booster for the HP compressor, enabling the latter component to be compact and lightweight.

(3) Losses can be minimised by use of optimised duct shapes and dimensions.

(4) As shown in Figures 5 to 7, the aircraft cabin itself can be used to carry some or all of the air from the load compressor to the HP compressor, because by using the heater/cooler 70A and/or 70C, all the air output from the load compressor 10 can be adjusted to the desired level of pressure and temperature for passenger comfort.

Although Figures 1 to 3 and 5 to 7 all show an HP compressor as well as the load compressor, this may not be necessary for all aircraft types. Aircraft with low electrical power requirements and/or requiring low quantities of air for the cabin air supply may not require a powerful generator 50, so a combustor burning fuel in low pressure air direct from load compressor 10 may provide sufficient power.

In interpreting the Figures 1 to 3 and 5 to 7, it should be remembered that they are schematic and that the layout will be optimised for particular aircraft installations. Therefore, the ducting joining the outlet of the load compressor 10 to the inlet of the HP compressor 20 and (in Figures 1,2,5 and 6 only) the ducting 26 and 29 joining the outlet of the HP compressor 20 to the recuperator 28 and the recuperator 28 to the combustor 30, may be much more compact than apparently indicated, and will certainly have curved bends instead of sharp corners.

Configuration 1

Referring now particularly to Figures 1 and 5, the load compressor 110, driven by motor 160, is sited in a convenient position next to an external surface 105 of an aircraft in which the auxiliary gas turbine engine is installed. The location may be, for example, the underside of the aircraft in front of or to the rear of a cargo or luggage hold. An air inlet 107 is provided in the surface 105, the inlet 107 being shaped to minimise distortion of the airflow into the load compressor 110. If required, the air inlet 107 may be provided with means, such as a mesh screen or inlet air particle separator (not shown), to prevent the ingestion of debris from the runway surface when the aircraft is on the ground.

As shown, the inlet 107 may be provided with an inlet air heater/cooler 170A, but its function may be supplemented or substituted for by air heater/coolers 170B or 170C located in alternative positions as mentioned above.

In configuration 1, the HP compressor 120 is driven through shaft 122 by an electric motor 124, which like motor 160 is powered from the generator 150. In the case of Figure 1, this enables the HP compressor 120 to be sited close to the load compressor 110, so minimising the length of the duct 112 between the compressors and hence reducing aerodynamic losses. In the case of the alternative implementation of configuration 1, shown in Figure 5, the aircraft cabin is utilised as a duct between load compressor 110 and HP compressor 120, so here the HP compressor 120 is placed closer to the other more downstream components of the auxiliary gas turbine engine, thereby reducing the length of ducting 126.

Ducting 126 carries the high pressure air from the outlet of HP compressor 120 to a recuperator 128. This comprises a heat exchange matrix built into ducting 145 which forms the outlet from the turbine 140. Passing through the recuperator 128, the high pressure air gains heat from exhaust gases exiting from the turbine 140. The recuperator 128 is provided to increase the efficiency of the engine cycle and enables fuel consumption to be reduced. If a lean burn combustion process is used, such pre-heating of the combustion air may also increase the stability of the combustion process.

Ducting 129 carries the heated high pressure air to the combustor 130. To minimise emissions of pollutants from the combustion process, the combustor is of the type known as a lean burn series staged combustor, in which sub-stoichiometric amounts of fuel are injected through successive arrays of injectors 131, 132, 133 into respective combustion stages for burning in the high pressure air, combustion only being completed in the last combustion stage. This enables careful control of combustion temperature in the successive stages to minimise production of oxides of nitrogen, while at the same time minimising production of carbon monoxide and unburned hydocarbons.

The products of combustion drive the turbine 140, and hence generator 150, before passing through ducting 145 and recuperator 128 to an exhaust nozzle 147 located in an external wall (not shown) of the aircraft. Preferably, the exhaust nozzle 147 is not located near to the air inlet 107 to avoid ingestion of the warm exhaust gases by the load compressor. The turbine/generator spool 140/155/150 may be located near to the external wall to minimise the length of the ducting 145, and hence duct aerodynamic losses, so avoiding excessive back pressure on the turbine 140.

Configurations 2 and 3

Referring now to Figures 2 and 6, configuration 2 will only be described insofar as it differs appreciably from configuration 1. The major difference from configuration 1 is the location of, and means for driving, the HP compressor 220. Specifically, the HP compressor 220 is driven directly by the turbine 240 through a shaft 222, instead of being driven by an electric motor powered by the generator. Hence, the HP compressor 220 is located close to the turbine 240 but is at a greater distance from the load compressor 210. Consequently, the ducting 212 joining the two compressors is shown longer than ducting 112 in configuration 1.

Referring now to Figures 3 and 7, configuration 3 will only be described insofar as it differs appreciably from configuration 2. The major differences from configuration 2 are the absences of a recuperator and a staged combustor. This enables adoption of a more compact arrangement of HP compressor 320 with combustor 330 and turbine 340, since the high pressure air from HP compressor 320 is fed directly to fuel injectors 331, 332 in an annular combustor 330 which circumscribes shaft 322. The combustion process may conveniently be of the rich burn rapid quench or rich burn diffusion controlled type. In the absence of preheating of combustion air by the exhaust gases from the turbine 340, they can exhaust via a duct 345 directly to atmosphere through exhaust nozzle 347.

Discussion of Thermodynamic Cycle Variations

The basic principle adopted is to obtain the required cabin pressure by running the load compressor 10 at a suitable pressure ratio and using the air heater/cooler 70A, 70B or 70C to adjust the cabin air temperature (taken from the load compressor exit through duct 15) to the required value. For each of the three basic configurations, the air heater/cooler can be placed in one or more of two or three possible positions, as previously mentioned.

First position of Air Heater/Cooler

- in the inlet 07 to the load compressor 10. In this position heater/cooler 70A has a reversible heat pump 74A acting as a cooler over most of the flight envelope, heating only being required on the coldest days at sea level. This position requires a lower cooling/heating power than if it is placed in the exit from the load compressor, since each 1°C change in inlet temperature is multiplied by the load compressor temperature ratio to produce a larger change in temperature at load compressor exit. When acting as a cooler, it also improves the cycle efficiency by reducing the power required to drive the compressors 10 and 20 to achieve the required pressure ratios.

It is a disadvantage for this location that the effects of the pressure loss through the heat exchanger matrix 72A are magnified by being at the inlet to the whole cycle.

A further disadvantage for this location is that the matrix would have to be provided with an anti-icing capability. One possible device to solve this problem comprises a microwave chamber, created by fitting gauzes to the matrix entry and exit: microwaves of the correct frequency (similar to that used for domestic microwave ovens) could then be generated inside this chamber, so melting any ice that forms without heating the air.

An alternative method for de-icing the heat exchange matrix 72A is periodically, as required, to run the heat pump in reverse for a short time to melt the ice. Alternatively, electric heating elements could be used. Such measures would temporarily degrade the efficiency of the engine and raise the temperature of the air at the outlet of the load compressor. However, the cabin air temperature could be corrected by use of the LP air heater/cooler 70C or the cabin air heater/cooler 70B, if present, in addition to the inlet air heater/cooler 70A. The cabin air heater/cooler 70B would not necessarily require much power input in order to correct the cabin air temperature, because electrical power could be used to pump coolant between the heat exchange matrix 72B and a further heat exchange matrix (not shown) located to reject heat to the atmosphere. If the engine included an LP air heater/cooler 70C at the exit of the load compressor instead of the cabin air heater/cooler 70B, heater/cooler 70C could be used to correct both the cabin air temperature and the temperature of the air being passed to the HP compressor 20. Again, this would not necessarily require much power, because heat from the heat exchange matrix 72C could be rejected to the atmosphere, in the same way as mentioned for heat exchange matrix 72B.

Second position of Air Heater/Cooler (Figures 1 to 3 only)

- in the cabin air supply duct 15 taking the air from the load compressor exit to the aircraft cabin. This requires less cooling/heating power than if placed in the other two positions, because of the smaller air mass flow rates. A heat exchanger transferring heat from the position in the cabin air supply duct 15 to ambient air would be sufficient over most of the flight envelope. Heating would be required on the coldest days at sea level, and refrigeration on days near or above standard sea level day temperatures. No air heater/cooler matrix pressure loss effects are felt by the cycle, apart from having to run the load compressor 10 at a higher pressure ratio in order to achieve the required cabin pressure.

No anti-icing would be necessary. However, no cycle efficiency benefits accrue from this position.

Third position of Air H at r/Cool r

- in the exit from the load compressor 10. Again, the heater/cooler 70C include a reversible refrigeration plant 74C. This position needs more cooling/heating power than the first position at the air inlet because of the multiplier effect of the load compressor temperature ratio. Even so, a heat exchanger transferring heat from the load compressor exit to ambient air would be sufficient over most of the flight envelope. Heating would be required on very cold days at sea level, and refrigeration on days near or above standard sea level day temperatures. Advantages are that the effects of loss of pressure in the air heater/cooler matrix are reduced, and no anti-icing would be needed. Some cycle efficiency benefits accrue when acting as a cooler due to reduction of the power necessary to drive the HP compressor. Overall however, this position for the heat exchanger matrix 72C is a third preference due to the requirement for greater cooling and heating power than the other two positions.

As already mentioned for anti-icing of the heat exchange matrix 70A, an air heater/cooler may be placed in more than one of the above positions, and heating or cooling carried out in the optimum position(s) for any given atmospheric and engine conditions.

Thermodynamic Cycle Details

Following are thermodynamic cycle data for configurations 1 to 3 in Figures 1 to 3, wherein the heat exchange matrix of the air heater/cooler is located in positions A or B mentioned above. Thermodynamic data in respect of the position C, at the outlet of the load compressor, will be listed later in respect of Figures 5 to 7.

(i) Heat Exchange Matrix in Inlet to load compressor

With a 5% pressure loss in the intake 07, a 6% pressure loss in the heater/cooler 70A and a 15% pressure loss in the duct 15 between load compressor exit and the aircraft cabin, the operating conditions of the load compressor 10 and air heater/cooler 70A at the conditions sea level static (SLS) and cruise (35000 feet, 0.8 Mach Number) on a standard day are as shown in Table 1.

TABLE 1

	SLS	Cruise
Inlet Air Mass Flow	12lb/s	≈7.7lb/s
Heater/Cooler Temperature Drop	14°C	30°C
Refrigeration Power	11kW	≈24kW
Inlet Flow Function ($W\sqrt{T}/P$)	15.1	≈24
Load Compressor Pressure Ratio	1.29	2.68
Load Compressor Power	132kW	≈300kW

Note that a compressor polytropic efficiency of 90% has been assumed. The load compressor 10 is conveniently powered by an electric motor 60, assumed to be 95% efficient (other methods are possible, including hydraulic, pneumatic or indirect mechanical drive), while the refrigeration plant 74A is assumed for calculation purposes to be an ammonia cycle with 10°C temperature drops across the evaporator and condenser heat exchangers; obviously, other more modern refrigerants with appropriate properties could be used instead. Note that, when the outside air temperature is significantly less than standard, the air heater/cooler will have to heat the air in order to obtain the correct cabin conditions. Alternatively, the air heater/cooler 70A could be switched off, and the load compressor could be run at a higher pressure ratio than before in order to produce the necessary outlet temperature. A throttle valve (not shown) in cabin air supply duct 15 could then be used to reduce the pressure to that required. This method has the disadvantage that more power would be required to drive the load compressor, thus increasing the size and weight of the motor 60 and generator 50.

Air from the exit from the load compressor 10 is also fed to the HP compressor 20. In Configuration 1, HP compressor 120 is positioned near the load compressor 110 and driven by its own electric motor 124, or alternatively it could be driven through gearing by the motor 160 which powers the load compressor. In configurations 2 and 3, HP compressor 20 is driven by a shaft 22 connected to the turbine 40; in the latter cases, extra ducting 12 may be required if the load compressor 10 and HP compressor 20 are positioned in different areas of the airframe. The pressure ratio of the HP compressor 20 has been selected such that, at the design point of the auxiliary gas turbine engine (sea level static, ISA with 15°C ambient temperature), the pressure ratio across the final nozzle is approximately 1.05; this has been done

to allow a reasonable size final nozzle to be fitted. The relevant performance parameters of the HP compressor are as shown in Table 2.

TABLE 2

	SLS	Cruise
Configuration 1	SLS	Cruise
Inlet Air Mass Flow	8.25lb/s	3.93lb/s
Inlet Flow Function (W√T/P)	8.46	5.41
HP Compressor Pressure Ratio	2.80	1.80
HP Compressor Power	454kW	114kW
Configuration 2		
Inlet Air Mass Flow	8.25lb/s	4.08lb/s
Inlet Flow Function (W√T/P)	10.52	6.97
HP Compressor Pressure Ratio	2.60	1.73
HP Compressor Power	396kW	105kW

TABLE 2 (CONTINUED)

Configuration 3	SLS	Cruise
Inlet Air Mass Flow	8.25lb/s	3.91lb/s
Flow Function (W√T/P)	10.52	6.69
HP Compressor Pressure Ratio	2.05	1.31
HP Compressor Power	286kW	47kW

A compressor polytropic efficiency of 90% has been assumed in all cases in Table 2. Note that the HP compressor power is electrical power (assuming a motor efficiency of 95%) in the case of configuration 1, but mechanical power in the cases of configurations 2 and 3. A duct loss of 20% between the load and HP Compressors has been assumed for configurations 2 and 3, but only 0.5% for configuration 1.

In Configurations 1 and 2, the air then enters a recuperator 28 (via a long duct 126, if necessary, in configuration 1). The purpose of the recuperator 28 is to use the energy in the gases leaving the turbine 40 to heat up the air from the HP compressor 20 before it enters the combustor 30, thus reducing the fuel required. The recuperator is assumed to introduce a 4% pressure drop, and have a 70% effectiveness; the relevant performance parameters are given in Table 3 below.

TABLE 3

	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	7.84lb/s	3.74lb/s
Temperature Rise	463°C	411°C
Heat Transfer	919CHU/s	383CHU/s
Configuration 2		
Inlet Air Mass Flow	7.84lb/s	3.88lb/s
Temperature Rise	483°	425°C
Heat Transfer	959CHU/s	411CHU/s

The slight reduction in airflow between HP compressor entry and recuperator entry is caused by a cooling air bleed of 5%, assumed to be necessary to keep the metal temperatures of the hot side of the recuperator within desirable values.

A combustion chamber 30 is provided in all three configurations, in which fuel is burned before entry to the turbine 40. The relevant combustion chamber performance parameters for all three configurations are given in Table 4 below.

TABLE 4

	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	7.84lb/s	3.74lb/s
Inlet Temperature	874K	769K
Temperature Rise	426°C	531°C
Outlet Temperature	1300K	1300K
Fuel Flow	346lb/hr	205lb/hr
Fuel/Air Ratio	.0123	.0152
Configuration 2		
Inlet Air Mass Flow	7.84lb/s	3.87lb/s
Inlet Temperature	885K	779K
Temperature Rise	415°C	521°C
Outlet Temperature	1300K	1300K
Fuel Flow	338lb/hr	208lb/hr
Fuel/Air Ratio	.0120	.0149
Configuration 3		
Inlet Air Mass Flow	8.25lb/s	3.91lb/s
Inlet Temperature	373K	323K
Temperature Rise	927°C	977°C
Outlet Temperature	1300K	1300K
Fuel Flow	760lb/hr	378lb/hr
Fuel/Air Ratio	.0255	.0268

In all cases, a combustion chamber pressure loss of 4% has been assumed, as well as 100% combustion efficiency and a fuel calorific value of 10222 CHU/lb. The level of outlet temperature (which equals the turbine entry temperature) is set at a level that, with modern materials, would require little or no turbine cooling air.

The products of combustion then enter the turbine, which extracts power from the hot, high-pressure gases leaving the combustion chamber to drive an electrical generator and, in Configurations 2 and 3, also provides shaft power to drive the HP compressor. The relevant performance parameters for the turbine in each of the three configurations are given in Table 5.

TABLE 5

	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	7.93lb/s	3.79lb/s
Inlet Flow Function (W√T/P)	8.24	8.24
Turbine Pressure Ratio	2.17	3.98
Turbine Non-Dimensional Power	.0432	.0717
Turbine Power	847kW	671kW
Generator Power	805kW	638kW

Continuation of the Table on the next page

TABLE 5 (continued)

	SLS	Cruise
Configuration 2		
Inlet Air Mass Flow	7.93lb/s	3.93lb/s
Inlet Flow Function (W√T/P)	8.92	8.92
Turbine Pressure Ratio	1.99	3.67
Turbine Non-Dimensional Power	.0388	.0681
Turbine Power	759kW	661kW
Generator Power	346kW	528kW
Configuration 3		
Inlet Air Mass Flow	8.46lb/s	4.02lb/s
Inlet Flow Function (W√T/P)	11.47	11.47
Turbine Pressure Ratio	1.72	3.06
Turbine Non-Dimensional Power	.0311	.0601
Turbine Power	650kW	596kW
Generator Power	346kW	521kW

In all cases, a turbine adiabatic efficiency of 89% has been assumed, as well as a generator efficiency of 95%. As explained above, the turbine is assumed to be uncooled at the level of turbine entry temperature (1300°K) selected.

The combustion products then pass into the hot side of the recuperator in configurations 1 and 2. Like the cold side, the hot side is assumed to introduce a 4% pressure drop. Table 6 gives the relevant performance parameters:-

TABLE 6

	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	8.35lb/s	3.99lb/s
Temperature Drop	406°C	361°C
Configuration 2		
Inlet Air Mass Flow	8.34lb/s	4.14lb/s
Temperature Drop	423°C	373°C

The slight rise in flow between the turbine exit and recuperator inlet is due to the return of the cooling air which was taken off immediately upstream of the cold side of the recuperator.

All three configurations then exhaust the combustion products through a duct 45, then through a final nozzle 47, with the characteristics shown in Table 7.

TABLE 7

	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	8.35lb/s	3.39lb/s
Nozzle Pressure Ratio	1.043	1.158
Nozzle Geometric Area	87.3 square inches	
Gross Thrust	107lbf	88lbf
Net Thrust	107lbf	-97lbf

TABLE 7 (continued)

Configuration 2	SLS	Cruise
Inlet Air Mass Flow	8.34lb/s	4.13lb/s
Nozzle Pressure Ratio	1.052	1.204
Nozzle Geometric Area	80.0 square inches	
Gross Thrust	117lbf	103lbf
Net Thrust	117lbf	-86lbf

Configuration 3		
Inlet Air Mass Flow	8.46lb/s	4.02lb/s
Nozzle Pressure Ratio	1.052	1.193
Nozzle Geometric Area	106.2 square inches	
Gross Thrust	157lbf	130lbf
Net Thrust	157lbf	-56lbf

In all cases, nozzle discharge coefficients of 0.99 and nozzle velocity coefficients of 0.99 have been assumed. The negative levels of net thrust (i.e. increases in drag) at cruise would be offset by the thrust produced when stale air is exhausted from the aircraft cabin through a separate nozzle: this force is normally accounted as 'negative' aircraft drag.

(ii) Heat Exchange Matrix in Cabin Air Supply Duct

Tables 8 to 14 give thermodynamic cycle details for the three configurations when the heat exchange matrix 72B of the heater/cooler 70B is in the cabin air supply duct 15 leading to the aircraft cabin. All the details of operation and assumptions made are identical to those given above, except that there is no heat exchanger matrix pressure loss at inlet to the load compressor 10 and the duct loss between load compressor exit and the aircraft cabin has been increased to 20% to allow for the presence of the heat exchanger matrix 72B. In cases where the ambient air temperature is appreciably lower than the desired cabin air temperature, a simple transfer of heat from the compressed air in duct 15 to the atmosphere surrounding the aircraft will lower its temperature sufficiently to obtain the desired cabin temperature. In cases where the cabin temperature is less than the ambient temperature, a refrigeration plant 74B, similar to that used in conjunction with heat exchanger matrix 72A, can be used to achieve the required extra cooling. The heat exchanger matrix is assumed to be able to cool the air in duct 15 to within 10°C of the ambient temperature. In cases where the load compressor exit temperature is lower than the desired cabin air temperature, heating of the air in the cabin air supply duct 15 can be accomplished either by a heat pump extracting heat from the atmosphere surrounding the aircraft or by electrical heating elements drawing power from the electrical generator.

TABLE 8

LOAD COMPRESSOR ENTRY	SLS	Cruise
Inlet Air Mass Flow	12lb/s	≈7.9lb/s
Inlet Flow Function (W√T/P)	14.59	≈25
Load Compressor Press. Ratio	1.26	2.63
Load Compressor Power	128kW	≈335kW

TABLE 9

HP COMPRESSOR ENTRY	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	8.25lb/s	4.25lb/s
Inlet Flow Function ($W\sqrt{T}/P$)	8.28	5.95
HP Compressor Pressure Ratio	2.60	1.80
HP Compressor Power	435kW	140kW
Configuration 2		
Inlet Air Mass Flow	8.25lb/s	4.33lb/s
Inlet Flow Function ($W\sqrt{T}/P$)	10.30	7.53
HP Compressor Pressure Ratio	2.40	1.69
HP Compressor Power	374kW	120kW

TABLE 9 (continued)	SLS	Cruise
Configuration 3		
Inlet Air Mass Flow	8.25lb/s	4.06lb/s
Flow Function ($W\sqrt{T}/P$)	10.30	7.07
HP Compressor Pressure Ratio	1.90	1.26
HP Compressor Power	264kW	46kW

TABLE 10

RECUPERATOR COLD SIDE	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	7.81lb/s	4.04lb/s
Temperature Rise	463°C	380°C
Heat Transfer	921CHU/s	385CHU/s
Configuration 2		
Inlet Air Mass Flow	7.84lb/s	4.11lb/s
Temperature Rise	483°C	397°C
Heat Transfer	962CHU/s	409CHU/s

TABLE 11

COMBUSTION CHAMBER	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	7.84lb/s	4.04lb/s
Inlet Temperature	882K	784K
Temperature Rise	418°C	516°C
Outlet Temperature	1300K	1300K
Fuel Flow	340lb/hr	215lb/hr
Fuel/Air Ratio	.0121	.0148
Configuration 2		
Inlet Air Mass Flow	7.84lb/s	4.11lb/s
Inlet Temperature	893K	793K
Temperature Rise	407°C	507°C
Outlet Temperature	1300K	1300K
Fuel Flow	332lb/hr	215lb/hr
Fuel/Air Ratio	.0118	.0145

TABLE 11 (continued)	SLS	Cruise
Configuration 3		
Inlet Air Mass Flow	8.25lb/s	4.06lb/s
Inlet Temperature	380K	360K
Temperature Rise	920°C	940°C
Outlet Temperature	1300K	1300K
Fuel Flow	753lb/hr	378lb/hr
Fuel/Air Ratio	.0253	.0258

TABLE 12

TURBINE	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	7.93lb/s	4.10lb/s
Inlet Flow Function (W√T/P)	8.50	8.50
Turbine Pressure Ratio	2.10	3.98
Turbine Non-Dimensional Power	.0414	.0718
Turbine Power	811kW	726kW
Generator Power	771kW	689kW
Configuration 2		
Inlet Air Mass Flow	7.93lb/s	4.17lb/s
Inlet Flow Function (W√T/P)	9.26	9.26
Turbine Pressure Ratio	1.92	3.66
Turbine Non-Dimensional Power	.0369	.0680
Turbine Power	722kW	700kW
Generator Power	331kW	551kW
Configuration 3		
Inlet air Mass Flow	8.46lb/s	4.17lb/s
Inlet Flow Function (W√T/P)	11.85	11.85
Turbine Pressure Ratio	1.67	3.04
Turbine Non-Dimensional Power	.0293	.0597
Turbine Power	612kW	614kW
Generator Power	331kW	540kW

TABLE 13

RECUPERATOR HOT SIDE	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	8.34lb/s	4.31lb/s
Temperature Drop	407°C	335°C
Configuration 2		
Inlet Air Mass Flow	8.34lb/s	4.39lb/s
Temperature Drop	424°C	349°C

TABLE 14

NOZZLE	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	8.34lb/s	4.31lb/s
Nozzle Pressure Ratio	1.047	1.211
Nozzle Geometric Area	83.7 square inches	
Gross Thrust	112lbf	111lbf
Net Thrust	112lbf	-82lbf

Continuation of the Table on the next page

TABLE 14   (continued)

NOZZLE	SLS	Cruise
Configuration 2		
Inlet Air Mass Flow	8.34lb/s	4.39lb/s
Nozzle Pressure Ratio	1.050	1.233
Nozzle Geometric Area	81.4 square inches	
Gross Thrust	116lbf	119lbf
Net Thrust	116lbf	-77lbf
Configuration 3		
Inlet Air Mass Flow	8.46lb/s	4.17lb/s
Nozzle Pressure Ratio	1.052	1.205
Nozzle Geometric Area	107.0 square inches	
Gross Thrust	157lbf	138lbf
Net Thrust	157lbf	-51lbf

Alternative Configurations 1 to 3, Figures 5 to 7.

In Figures 1 to 3, the cabin air supply duct 15 is an offtake from the main air flow in duct 12 between load compressor 10 and HP compressor 20. However, all three alternative implementations in Figures 5 to 7 use the aircraft cabin to carry some or all of the air from the load compressor to the HP compressor. Relative to Figures 1 to 3 respectively, ducting 12 is replaced by optional ducting 12' (necessary only to reduce the pressure ratio of the turbine 40 as explained below), the cabin air heater/cooler 70B has been removed, and the connection between the load compressor 10 and the HP compressor 20 is made through the aircraft cabin 13. This is feasible since, for all configurations with heater/coolers in positions A and/or C, the pressure and temperature of the air passing between the load compressor 10 and the HP compressor 20 is at the required values for passenger comfort.

The advantage of these alternative implementations is that the airflow through the auxiliary gas turbine engine is greatly reduced relative to Figures 1 to 3, resulting in smaller and lighter components. Their disadvantage is that much higher turbine 40 pressure ratios are needed, because the electrical offtake power to the rest of the aircraft is a much higher fraction of the power output of the generator 50. Turbine pressure ratios can be reduced by either supplying more airflow through the aircraft cabin, or by introducing ducting 12' in parallel to the cabin 13, thereby increasing the airflow that can pass from the load compressor 10 to the HP compressor 20.

Tables 15 to 21 give thermodynamic cycle data for alternative implementations of configurations 1 to 3 in Figures 5 to 7 respectively, assuming that the heater/cooler 70A is situated to heat or cool the air before it enters the load compressor 10. All other operational details and assumptions made are as previously stated with reference to Figures 1 to 3, except that a 5% pressure loss has been introduced between the aircraft cabin outlet and the HP compressor, and allowance has been made for metabolic heat from the aircraft occupants (assumed to be 100 Watts each). Note that alternative implementation of configuration 1 in Figure 5 is only practical if aerodynamic losses in duct 126 are kept low; it may therefore offer few, if any, advantages over the alternative implementation of configuration 2 shown in Figure 6.

TABLE 15

LOAD COMPRESSOR ENTRY	SLS	Cruise
Inlet Air Mass Flow	3.75lb/s	3.75lb/s
Inlet Flow Function (W√T/P)	4.73	11.74
Load Compressor Press. Ratio	1.29	2.68
Load Compressor Power	41kW	144kW

TABLE 16

HP COMPRESSOR ENTRY	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	3.75lb/s	3.75lb/s
Inlet Flow Function (W√T/P)	4.72	6.32
HP Compressor Pressure Ratio	6.00	7.71
HP Compressor Power	423kW	503kW
Configuration 2		
Inlet Air Mass Flow	3.75lb/s	3.75lb/s
Inlet Flow Function (W√T/P)	4.72	6.32
HP Compressor Pressure Ratio	4.00	4.92
HP Compressor Power	291kW	346kW
Configuration 3		
Inlet Air Mass Flow	3.75lb/s	3.75lb/s
Inlet Flow Function (W√T/P)	4.72	6.32
HP Compressor Pressure Ratio	3.10	3.64
HP Compressor Power	227kW	267kW

TABLE 17

RECUPERATOR COLD SIDE	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	3.56lb/s	3.56lb/s
Temperature Rise	264°C	86°C
Heat Transfer	240CHU/s	78CHU/s

TABLE 17 (Continued)

	SLS	Cruise
Configuration 2		
Inlet Air Mass Flow	3.56lb/s	3.56lb/s
Temperature Rise	362°C	135°C
Heat Transfer	328CHU/s	120CHU/s

TABLE 18

COMBUSTION CHAMBER	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	3.56lb/s	3.56lb/s
Inlet Temperature	805K	670K
Temperature Rise	495°C	524°C

Continuation of the Table on the next page

TABLE 18   (continued)

COMBUSTION CHAMBER	SLS	Cruise
Configuration 1		
Outlet Temperature	1300K	1193K
Fuel Flow	182lb/hr	187lb/hr
Fuel/Air Ratio	.0142	.0146
Configuration 2		
Inlet Air Mass Flow	3.56lb/s	3.56lb/s
Inlet Temperature	839K	643K
Temperature Rise	461°C	454°C
Outlet Temperature	1300K	1097K
Fuel Flow	170lb/hr	159lb/hr
Fuel/Air Ratio	.0133	.0124
Configuration 3		
Inlet Air Mass Flow	3.56lb/s	3.56lb/s
Inlet Temperature	440K	463K
Temperature Rise	860°C	553°C
Outlet temperature	1300K	1017K
Fuel Flow	305lb/hr	188lb/hr
Fuel/Air Ratio	.0238	.0146

TABLE 19

TURBINE	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow	3.61lb/s	3.61lb/s
Inlet Flow Function ($W\sqrt{T}/P$)	1.70	1.70
Turbine Pressure Ratio	4.78	11.34
Turbine Non-Dimensional Power	.0795	.1113
Turbine Power	709kW	912kW
Generator Power	674kW	866kW
Configuration 2		
Inlet Air Mass Flow	3.61lb/s	3.61lb/s
Inlet Flow Function ($W\sqrt{T}/P$)	2.55	2.55
Turbine Pressure Ratio	3.18	7.43
Turbine non-Dimensional Power	.0617	.0962
Turbine Power	550kW	723kW
Generator Power	246kW	358kW
Configuration 3		
Inlet Air Mass Flow	3.65lb/s	3.62lb/s
Inlet Flow Function ($W\sqrt{T}/P$)	3.17	3.17
Turbine Pressure Ratio	2.70	6.72

Continuation of the Table on the next page

TABLE 19 (continued)

TURBINE	SLS	Cruise
Configuration 3		
Turbine Non-Dimensional Power Turbine Power Generator Power	.0540 486kW 246kW	.0922 643kW 358kW

TABLE 20

RECUPERATOR HOT SIDE	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow Temperature Drop	3.80lb/s 236°C	3.80lb/s 78°C
Configuration 2		
Inlet Air Mass Flow Temperature Drop	3.80lb/s 321°C	3.80lb/s 123°C

TABLE 21

NOZZLE	SLS	Cruise
Configuration 1		
Inlet Air Mass Flow Nozzle Pressure Ratio Nozzle Geometric Area Gross Thrust Net Thrust	3.80lb/s 1.045 39.6 square inches 50lbf 50lbf	3.80lb/s 1.793 170lbf 79lbf
Configuration 2		
Inlet Air Mass Flow Nozzle Pressure Ratio Nozzle Geometric Area Gross Thrust Net Thrust	3.80lb/s 1.045 38.9 square inches 50lbf 50lbf	3.79lb/s 1.747 159lbf 68lbf
Configuration 3		
Inlet Air Mass Flow Nozzle Pressure Ratio Nozzle Geometric Area Gross Thrust Net Thrust	3.84lb/s 1.048 47.6 square inches 64lbf 64lbf	3.80lb/s 1.567 154lbf 63lbf

Aircraft Types suitable for Configurations 1 to 3

All three configurations have features which may make each more suited to particular types of aircraft.

Configuration 1 is suitable for a small aircraft in which, because the demands are lower, the machinery will be smaller and lighter and the increased configurational flexibility offered by the non-mechanical driving connection of the HP compressor may make installation easier.

Configuration 2 is suitable for a long-range aircraft, in which the extra weight of the recuperator is more than offset by the fuel savings that result.

Configuration 3 is suitable for a short-haul aircraft, for which weight and complexity savings are more important than fuel savings.

Aircraft Equipment Changes Relative to Current Practice

Some equipment currently installed on aircraft which have APUs can be deleted if the auxiliary gas turbine engines of the present invention are installed in place of conventional APUs. Such equipment is:

(a) Main engine air offtake systems for aircraft pressurisation and air supply and the associated ducting in engine support pylons, wings and fuselage.

(b) Current air conditioning packs, required for pressure reduction and temperature adjustment of air taken from the main engines.

To maximise the benefits accruing from use of the auxiliary gas turbine engines described above, air offtakes and ducting for supply of hot air to aircraft flying surfaces to combat ice formation should also be deleted. Such ducting, coming from engines or APUs, is present in wings and tail surfaces and includes associated safety features, such as blow-off panels and isolation valves. To replace these conventional anti-icing measures, it is suggested that known types of electrical de-icing systems be installed, such as electrical impulse or thin film resistance elements, powered from the generators 50 in the auxiliary gas turbine engines.

Claims

1. An auxiliary gas turbine engine for an aircraft, including;
   an air intake (107),
   a load compressor (110) for compressing air supplied from the air intake,
   a cabin air supply duct (115) for supplying air from the load compressor to a cabin (113) of the aircraft,
   a combustor (130) for burning fuel in air supplied from the load compressor,
   a turbine (140) driven by the combustion products of the combustor, and
   turbine exhaust means (145,147);
   characterised by
   variable speed drive means (150,124) for transferring power from the turbine (140) to drive the load compressor (110), and
   heat exchanger means (170A,170B,170C) for adjusting the temperature of the air flowing through the cabin air supply duct (115).

2. An engine according to claim 1, in which the load compressor is in flow series with a high pressure (HP) compressor, the load compressor supplying air to the cabin air supply duct and the HP compressor supplying air to the combustor.

3. An engine according to claim 1, in which the load compressor is the sole compressor in flow series with the combustor.

4. An engine according to claim 2, in which the HP compressor is driven directly by the turbine.

5. An engine according to claim 2, in which the HP compressor is driven by transfer of power from the turbine through further variable speed drive means.

6. An engine according to claim 2, in which the load compressor is positioned remotely from the HP compressor and ducting is provided to carry air between the compressors.

7. An engine according to claim 3, in which the load compressor is positioned remotely from the combustor and ducting is provided to carry air between the load compressor and the combustor.

8. An engine according to claim 5, in which the HP compressor is positioned remotely from the combustor and ducting is provided to carry air between the compressor and the combustor.

9. An engine according to any preceding claim, in which ducting provided to carry at least some of the air between the load compressor and subsequent components of the auxiliary gas turbine engine includes a cabin of the aircraft.

10. An engine according to any preceding claim, in which the variable speed drive means for transmitting power from the turbine to the load compressor comprises an electrical generator driven directly by the turbine, and an electric motor driven by the electrical output of the generator, the electric motor in turn driving the compressor.

11. An engine according to claim 5, in which the further variable speed drive means for transmitting power from the turbine to the HP compressor comprises an electrical generator driven directly by the turbine, and an electric motor driven by the electrical output of the generator, the electric motor in turn driving the compressor.

12. An engine according to claim 10 or claim 11, in which the electrical generator is adapted to supply the electrical power requirements of the aircraft.

13. An engine according to any preceding claim, in which the heat exchanger means includes heat pump means powered through drive means from the turbine.

14. An engine according to claim 13, in which the drive means for the heat pump comprises an electric motor driven by the turbine-driven electrical generator.

15. An engine according to any preceding claim, in which the heat exchanger means includes at least one heat exchanger matrix located before and/or after the load compressor.

16. An engine according to claim 15, in which the heat exchanger matrix incorporates electrical heating elements powered from the generator.

17. An engine according to any preceding claim, in which a heat exchanger matrix of the heat exchanger means is located in the air intake to adjust the air temperature before it enters the load compressor.

18. An engine according to any one of claims 1 to 16, in which a heat exchanger matrix of the heat exchanger means is located in the cabin air supply duct to adjust the air temperature after it has passed through the load compressor but before it is used for air conditioning of the aircraft.

19. An engine according to any one of claims 1 to 16, in which a heat exchanger matrix of the heat exchanger means is located at the outlet of the load compressor to heat or cool all the air after it has passed therethrough.

20. An engine according to any one of claims 1 to 16, in which a heat exchanger matrix of the heat exchanger means is located in the air intake to adjust the air temperature before it enters the load compressor and a further heat exchanger matrix is located in the cabin air supply duct to further adjust the air temperature after it has passed through the load compressor but before it is used for air conditioning of the aircraft.

21. An engine according to any one of claims 1 to 16, in which a heat exchanger matrix of the heat exchanger means is located in the air intake to adjust the air temperature before it enters the load compressor and a further heat exchanger matrix is located at the exit from the load compressor to further adjust the air temperature after it has passed through the load compressor but before it is used for air conditioning of the aircraft.

22. An engine according to any preceding claim, in which an exhaust heat recuperator is employed to preheat the air for combustion before it enters the combustor.

23. An engine according to claim 22, in which the recuperator comprises a heat exchange matrix built into an outlet duct from the turbine.

24. An engine according to any preceding claim, in which the combustor is arranged to support a lean burn type of combustion process.

25. An auxiliary gas turbine engine for a passenger carrying aircraft, comprising:
a load compressor (110);
a cabin air supply duct (115) for supplying at least some of the air from the load compressor to a passenger

cabin (113) of the aircraft;

a combustor (130) for burning fuel in the air supplied from the load compressor to produce combustion gases;

a turbine (140) for extracting power from the combustion gases; and

an electrical generator (150) driven by the turbine for supplying electrical power to the aircraft;

characterised by

a high pressure compressor (120) for further compressing the air from the load compressor (110) before it is passed to the combustor;

an electric motor (124) driven by the electrical output of the generator (150), the electric motor in turn driving the load compressor (110); and

at least one heater/cooler (170A,170B,170C) for heating or cooling the air before or after it passes through the load compressor, the at least one heater/ cooler comprising a heat exchanger matrix (172A,172B,172C) for exchanging heat with air flowing therethrough and a reversible heat pump (174A,174B,174C) electrically powered from the generator so that it can cool or heat the air passing through the matrix, the load compressor and the at least one heat exchanger being adapted to produce air at the required pressure and temperature for supply to the aircraft passenger cabin (113).

26. An engine according to claim 25, in which an exhaust heat recuperator is employed to preheat the air for combustion before it enters the combustor.

27. An engine according to claim 26, in which the recuperator comprises a heat exchange matrix built into an outlet duct from the turbine.

28. An engine according to any one of claims 25 to 27, in which the passenger cabin is utilised to carry at least some of the air between the load compressor and the high pressure compressor.

29. An aircraft having installed therein an auxiliary gas turbine engine according to any preceding claim.
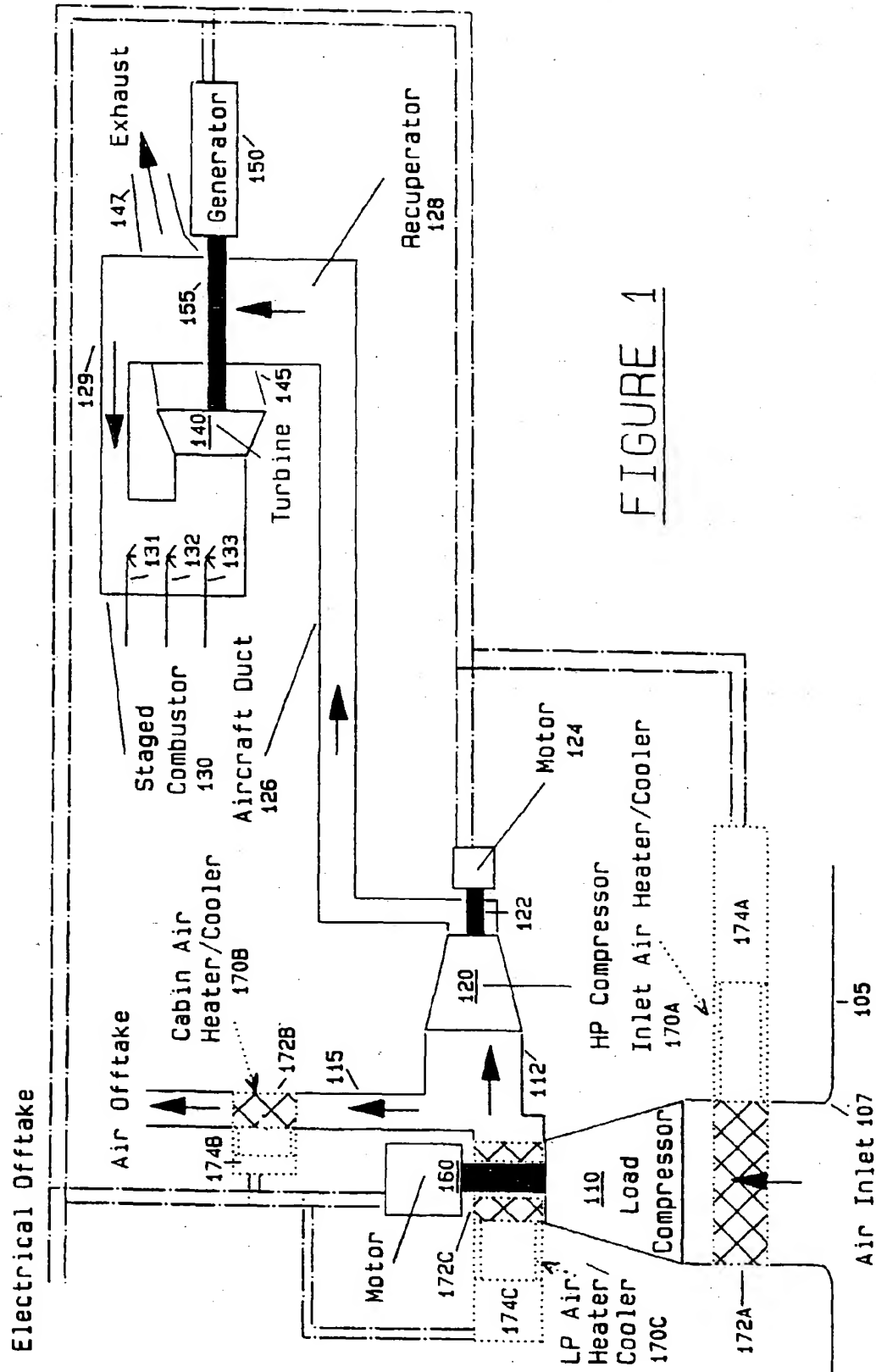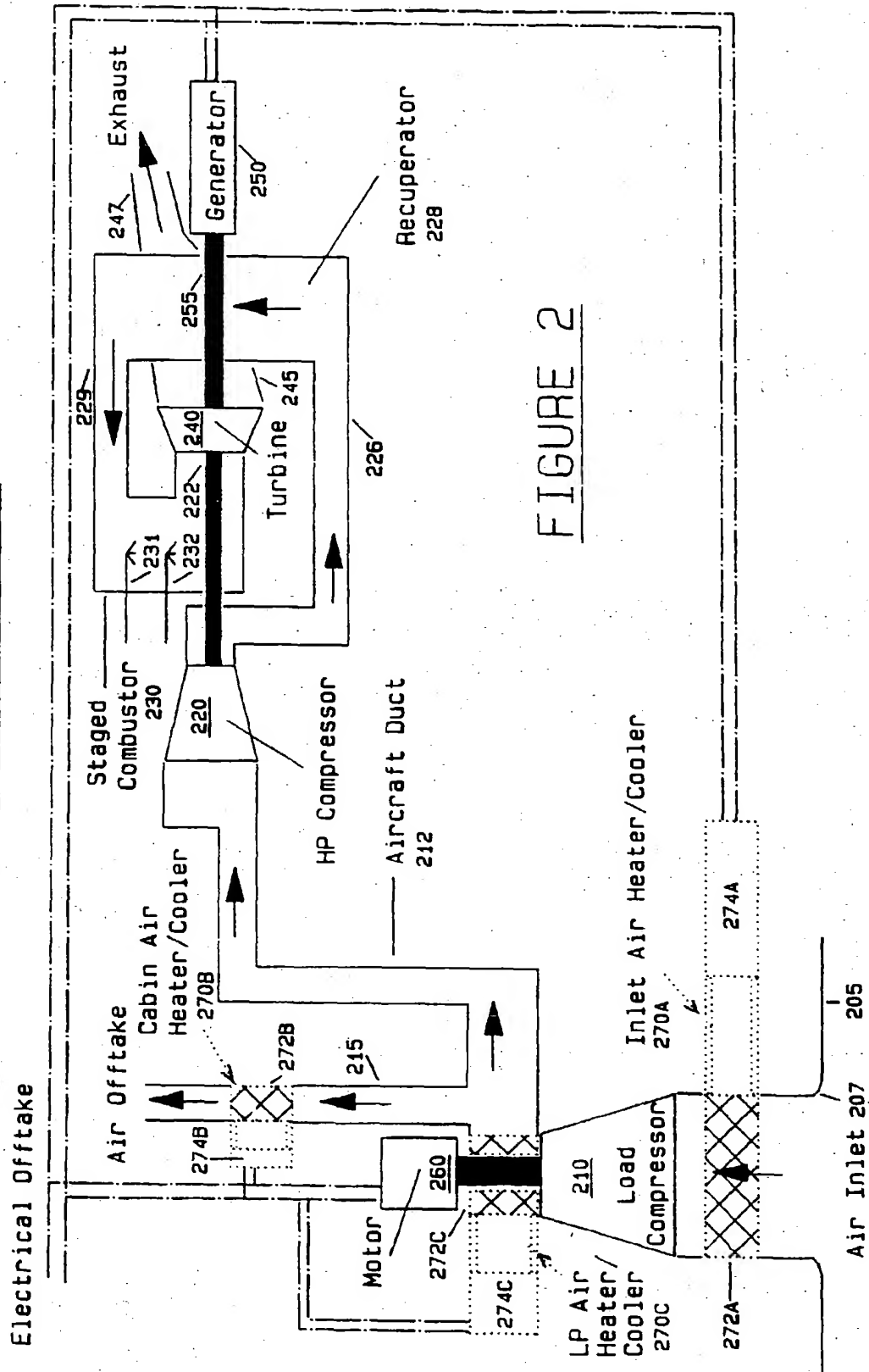
CONFIGURATION 1

Electrical Offtake

Air Exhaust 147

Generator 150

Recuperator 128

155

129

140

Turbine 145

131
132
133

Staged Combustor 130

Aircraft Duct 126

Motor 124

122

120

HP Compressor
Inlet Air Heater/Cooler 170A

174A

105

112

Cabin Air Heater/Cooler 170B

Air Offtake

172B

174B

115

160

Motor

172C

174C

110
Load Compressor

172A

Air Inlet 107

LP Air Heater/Cooler 170C

FIGURE 1

CONFIGURATION 2

FIGURE 2

CONFIGURATION 3
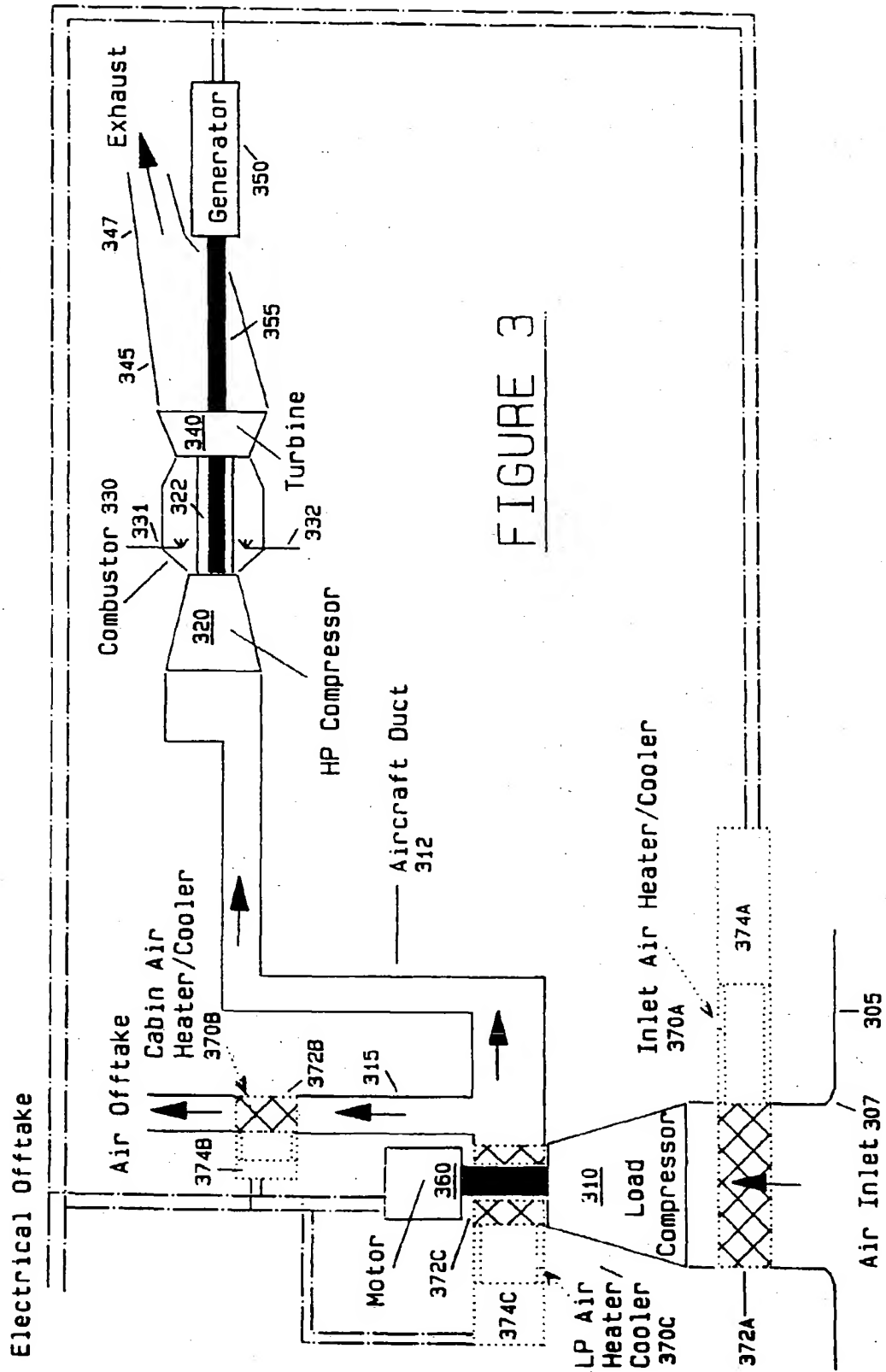
FIGURE 3

CONVENTIONAL APU CONFIGURATION

Exhaust
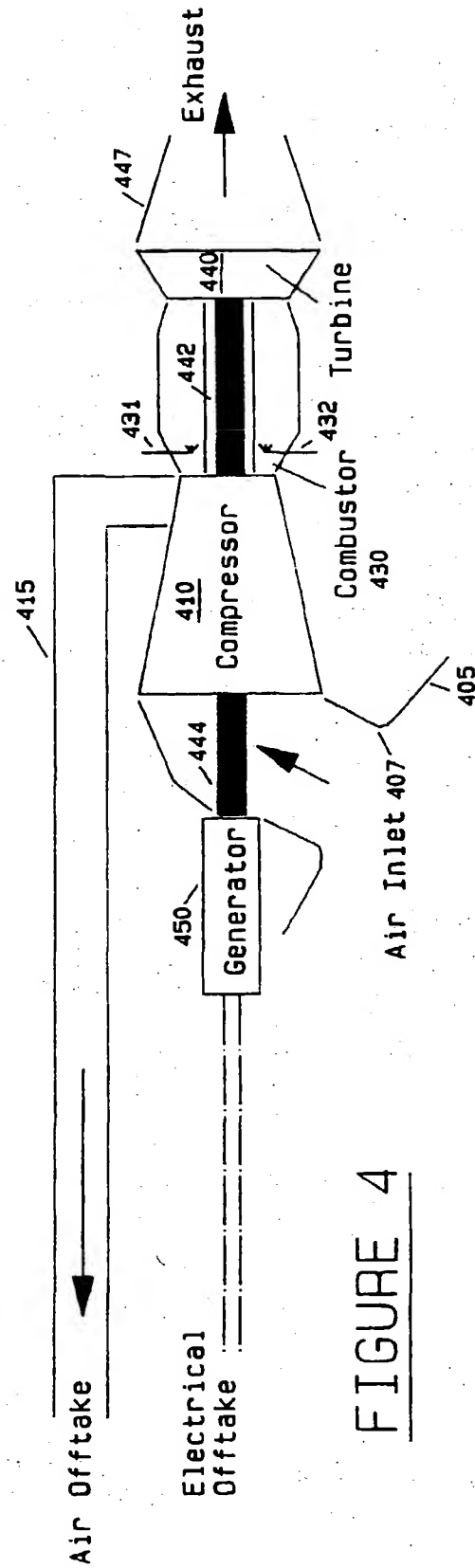
447

440

442

431

Combustor 432 Turbine
430

415

410
Compressor

444

450

Generator

405

Air Inlet 407

Air Offtake

Electrical
Offtake

FIGURE 4

ALTERNATIVE CONFIGURATION 1

Electrical Offtake

147 Exhaust

Generator
150

Recuperator
128

155

129

Turbine 145

140

Motor
124

131
132
133

122

Staged
Combustor
130

Aircraft Duct
126

HP Compressor

120

Aircraft Cabin
113

Inlet Air Heater/Cooler
170A

174A

112'

105

115

Motor

160

Load
Compressor

110

Air Inlet 107

172C

174C

LP Air
Heater/
Cooler
170C

172A
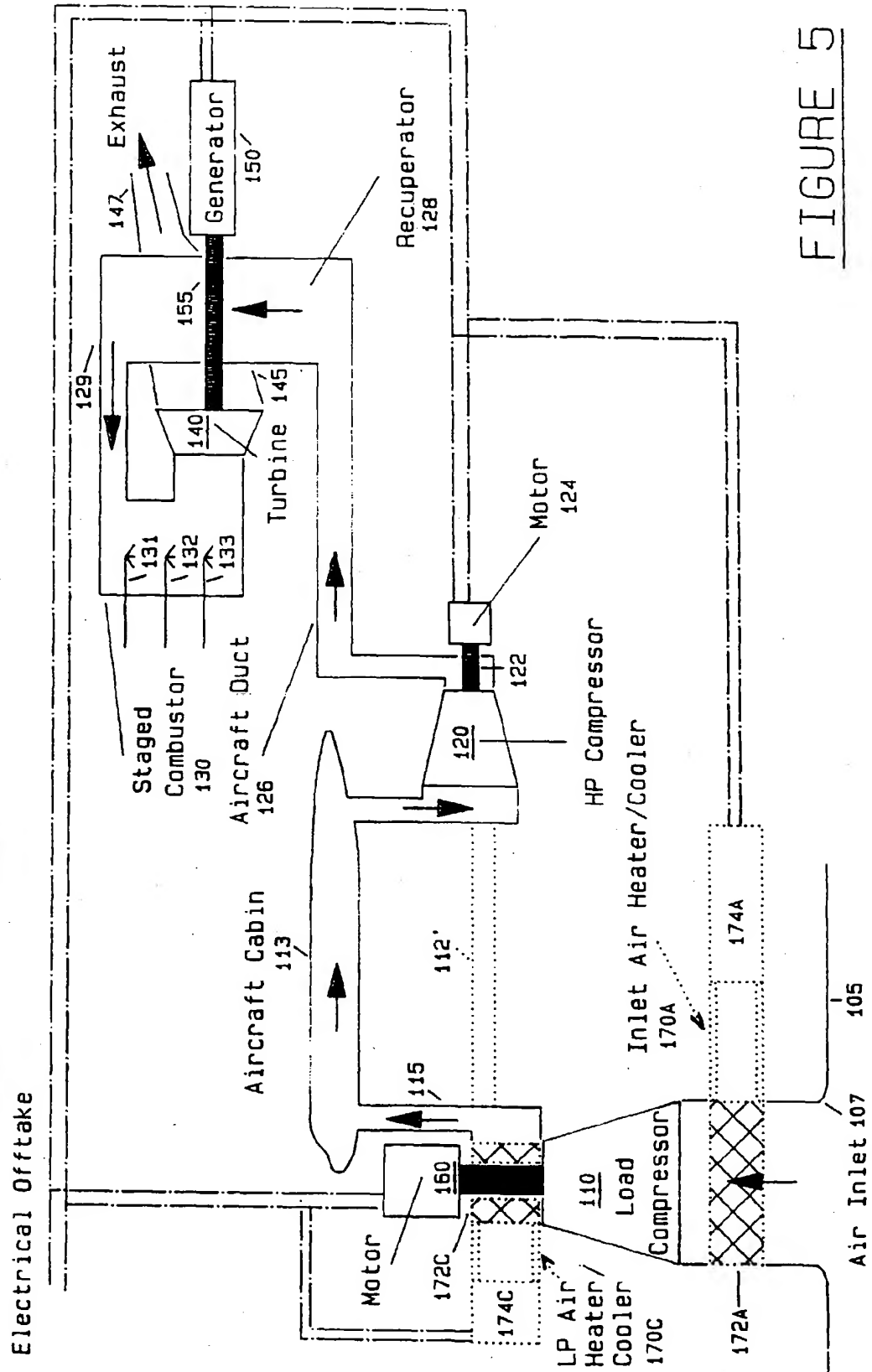
FIGURE 5

ALTERNATIVE CONFIGURATION 2

FIGURE 6

ALTERNATIVE CONFIGURATION 3

Electrical Offtake

Exhaust

Generator 350

347

355

345

340 Turbine

322

331 Combustor 330

332

320

HP Compressor

Aircraft Cabin 313

312'

315

Inlet Air Heater/Cooler 370A

374A

305

Motor

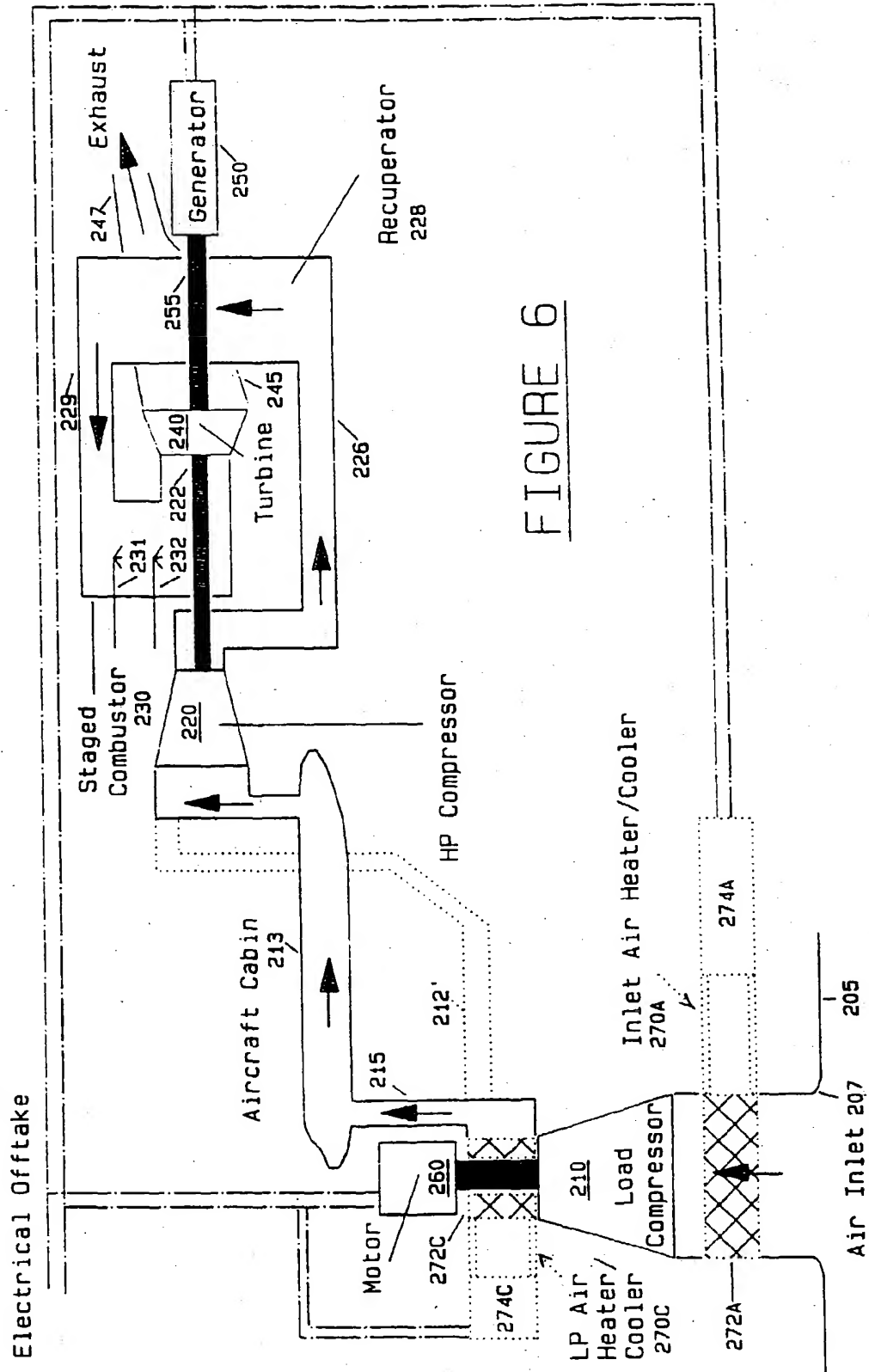360

372C

374C

310 Load Compressor

LP Air Heater/ Cooler 370C
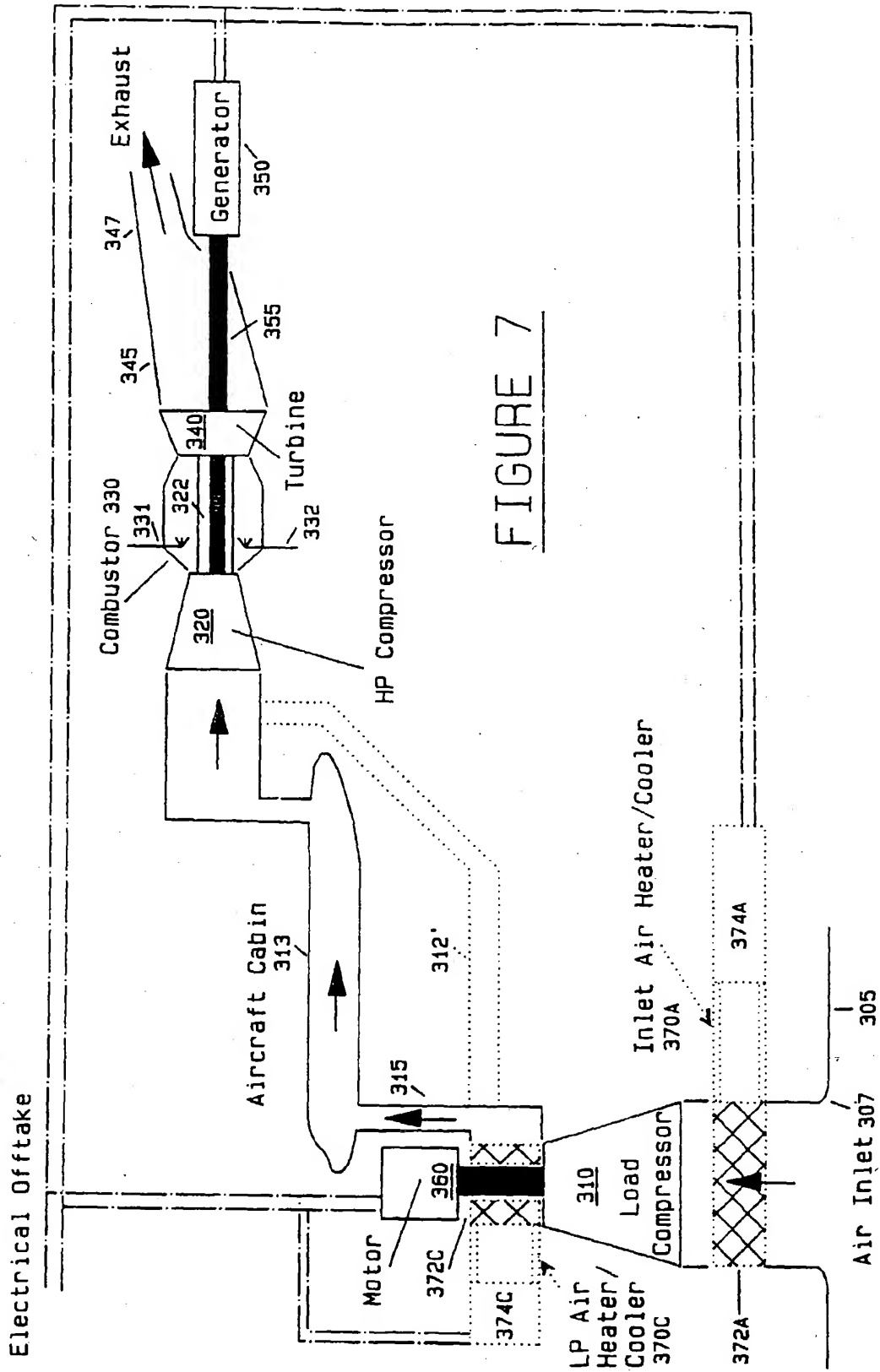
372A

Air Inlet 307

FIGURE 7

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 95 30 4674

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	US-A-2 618 470 (BROWN) * column 1, line 38 - column 2, line 31 * ---	1	B64D41/00
Y	US-A-3 997 283 (KRONOGARD) * column 1, line 30 - line 36 * ---	1	
A	FR-A-2 076 450 (SOCIETE NATIONALE D'ETUDE ET DE CONSTRUCTION DE MOTEURS D'AVIATION) * claim 1 * ---	1	
A	US-A-4 503 666 (CHRISTOFF) * the whole document * -----	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6) B64D F24F F02C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	13 October 1995	Hauglustaine, H

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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    document of the same category
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    document

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